Computing Flood Discharges

For Small Ungaged Watersheds

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This report supercedes and replaces all previous versions that describe this method, including *Computing Flood Discharges For Small Ungaged Watersheds* (Sorrell and Hamilton, September 1991, July 2000, October 2001) as well as *SCS UD-21 Method* (Sorrell, 1980 and 1985).

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1. INTRODUCTION

Concern for potential flooding is a critical factor in the safe design of water-related projects. The magnitudes of floods are described by flood discharge, flood elevation, and flood volume. This report will detail a procedure that can be used to estimate both the discharge and volume of a flood given a design rainfall and a physical description of the watershed.

There are a variety of methods for estimating design floods. They can be grouped into three general categories.

1. Statistical analysis of gage data

   This method is used for streams which have a number of years of recorded flood data. It involves fitting a probability distribution to the data (usually the log-Pearson Type III) and using the parameters of the distribution to estimate large floods. Since this method utilizes actual flood data, it is generally regarded as the best estimator of design floods and should be used whenever possible.

2. Regression analysis

   This method involves correlating watershed characteristics to streamflow using data from a number of gaged streams. The predicting equation derived from this type of analysis usually expresses flood discharge as a function of multiple watershed characteristics. These equations almost always include drainage area as the most significant factor and may also include channel slope, precipitation intensity, and other characteristics related to land uses, soil types, and geologic formations in the watershed. This method can be used for ungaged stream locations.

3. Unit hydrograph techniques

   This method involves determining the peak rate of runoff, Q_p, expressed in cubic feet per second (cfs) per inch of runoff from a given drainage area. This factor is primarily a function of the time it takes for runoff to travel through the basin to the design point. Once this rate of runoff is determined, it can be multiplied by the amount of runoff to produce a discharge. The versatility of this method is that it can

account for changes in watershed travel time, and subsequently Q_p, that are caused by alterations in the hydraulic capacity of the stream, such as channel maintenance operations, flood control structures, etc. The volume of runoff from a given amount of rainfall can also be adjusted to reflect changing land use within a watershed. This method is also suitable for ungaged watersheds.

This report presents a method for computing flood discharges using unit hydrograph (UH) techniques. The procedure is similar to that developed by the U.S. Soil Conservation Service (SCS) and described in the National Engineering Handbook, Hydrology: Section 4 (1972).

The advantage of this method is that it is straightforward to apply and the physical parameters are easily determined. The primary disadvantage is that the method presented here is only valid for use with a 24-hour rainfall. For other rainfall durations, one should follow the full procedure in the SCS reference. This method should also be limited to watersheds with a drainage area of approximately 20 mi^2 or less. One of the reasons for this limit is that UH theory assumes uniform rainfall and runoff from the entire drainage basin. This assumption is less reliable if the drainage area becomes too large. If a large watershed is being analyzed, it should be divided into subbasins and the flows from the individual subareas routed to the design location.

The physical description of the watershed includes drainage area, soil types, land uses, and time of concentration. These are discussed in subsequent sections of this report.

A comprehensive application of this method is presented in Appendix A.

2. THE UNIT HYDROGRAPH

The unit hydrograph theory was first proposed by Sherman (1932). It is defined as a surface runoff hydrograph (SRH) resulting from one inch of excess rainfall generated uniformly over the drainage area at a constant rate for an effective unit time duration. Sherman originally used the word "unit" to denote a unit of time, but since then it has often been interpreted as a unit depth of excess rainfall. Sherman classified streamflow into surface runoff and groundwater runoff or baseflow. The UH is defined for use only with surface runoff. When analyzing a recorded flood hydrograph, the baseflow contribution should be subtracted from the total flow before deriving the UH. Likewise, when using a UH to compute a design flow, a baseflow should be added to obtain the total design discharge.

The following basic assumptions are inherent to the UH:

1. The excess rainfall has a constant intensity within the unit duration.

2. The excess rainfall is uniformly distributed throughout the whole drainage area.

3. The base time of the SRH (the duration of surface runoff) resulting from an excess rainfall of a given duration is constant.

4. The ordinates of all SRH's of a common base time are directly proportional to the total amount of surface runoff represented by each hydrograph.

5. For a given watershed, the hydrograph resulting from a given excess rainfall reflects the unchanging characteristics of the watershed.

Assumption 3 implies that all 24-hr rainfalls will produce a SRH where the time to peak and base time of the SRH remain constant. Assumption 4 implies that if the ordinates of the UH represent one inch of runoff, then a hydrograph representing two inches of runoff is obtained by simply multiplying each ordinate of the UH by 2. If all unit hydrographs conform to a constant shape, that is, a constant amount of volume under the rising limb of the UH, then both the time and discharge ordinates can be normalized to produce a dimensionless UH. The SCS has examined many hydrographs nationwide and computed a standard dimensionless UH which has 37.5 percent of the volume under the rising limb. This volume has been known to vary, according to the SCS, in the range of 23 to 45 per cent.

Over the years, use of the SCS dimensionless hydrograph consistently overestimates discharges when compared to recorded gage flows for Michigan streams. To partially compensate for this, the SCS Type I rainfall distribution has been used in place of the recommended, but more intense, Type II distribution. A review of hourly rainfall data shows, however, that the Type II distribution is the appropriate one to use. Therefore, a study has been done to evaluate whether the shape of the standard SCS dimensionless UH is applicable to Michigan streams.

This study involved 24 gaged streams with drainage areas less than 50 mi^2. Seventy-four different flood events were analyzed. The results from this study demonstrate that the recorded floods are best reproduced if the SCS UH has 28.5 percent of the volume under the rising limb. This value is within the SCS's acknowledged range for this parameter.

3. DESIGN RAINFALL

Atlases are available from various governmental agencies which provide design rainfall amounts for durations from 30 minutes to 24 hours and recurrence intervals from 1 to 100 years. Normal practice in Michigan has been to use 24 hours as the design rainfall duration. Until recently, the rainfall amounts have been taken almost exclusively from Hershfield (1961), commonly known as the U.S. Weather Bureau's technical paper TP-40.

However, rainfall amounts well in excess of the frequency predicted by TP-40 have been occurring in Michigan and throughout the country for a number of years. Part of the reason may be that TP-40 utilized a shorter data set ending in 1958. Sorrell and Hamilton (1991) analyzed 24-hour rainfall data through 1986 for Michigan gages in order to update the TP-40 information. Huff and Angel (1992) also analyzed rainfall data for the Midwest, including Michigan, for durations from 5-minutes to 10-days. The 24-hour results from these two studies are similar.

Since the Huff and Angel study cover more durations and frequencies, we recommend its use to obtain design rainfall for the method presented in this report.

The Huff and Angel study divided the state into 10 climatic sections that correspond to the weather forecast divisions used by the National Weather Service at that time. These 10 climatic zones are depicted in Figure 3.1. The rainfall frequency data for each climatic section is presented in Table 3.1. To use this map and table, you should locate your design point in Figure 3.1 and use the corresponding climatic section number to obtain the rainfall amounts from the corresponding Section in Table 3.1. If the watershed straddles two or more climatic zones, use the rainfall for the zone that contains the largest percentage of the total drainage area.

The design rainfall data are point estimates and must be adjusted if the drainage area is greater than 10 square miles. The adjustment ratio, listed in Table 3.2, accounts for uncertainty in the areal distribution. These adjustment ratios are taken from Table 21.1 in the SCS National Engineering Handbook reference. Values for intermediate drainage areas may be interpolated in the table.

Figure 3.1 Climatic Zones for Michigan
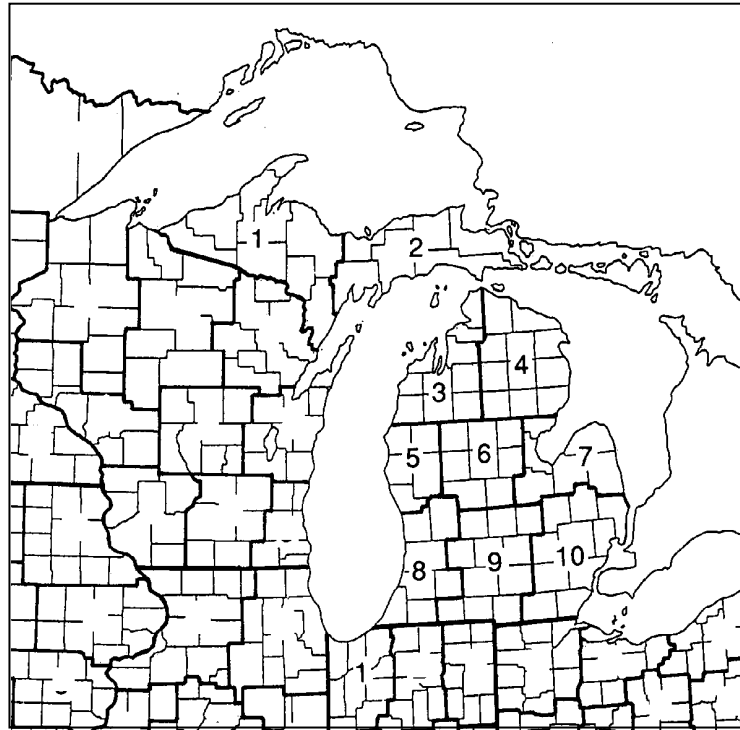
Table 3.1 Rainfall amounts corresponding to the climatic zones in Table 3.1 from the Rainfall
Frequency Atlas of the Midwest, Huff and Angel (1992)

	Rainfall frequencies, 24-hour duration (rainfall in inches)					
Zone	2-year	5-year	10-year	25-year	50-year	100-year
1	2.39	3.00	3.48	4.17	4.73	5.32
2	2.09	2.71	3.19	3.87	4.44	5.03
3	2.09	2.70	3.21	3.89	4.47	5.08
4	2.11	2.62	3.04	3.60	4.06	4.53
5	2.28	3.00	3.60	4.48	5.24	6.07
6	2.27	2.85	3.34	4.15	4.84	5.62
7	2.14	2.65	3.05	3.56	3.97	4.40
8	2.37	3.00	3.52	4.45	5.27	6.15
9	2.42	2.98	3.43	4.09	4.63	5.20
10	2.26	2.75	3.13	3.60	3.98	4.36

Table 3.2 Ratios for areal adjustment of point rainfalls.

Area (mi^2)	Ratio
10	1.00
15	.978
20	.969
25	.964
30	.960
35	.957
40	.953

4. SOIL TYPE

Soil properties influence the process of generating runoff from rainfall and must be considered in methods of runoff estimation. When runoff from individual storms is the major concern, the properties can be represented by a hydrologic parameter which reflects the minimum rate of infiltration obtained for a bare soil after prolonged wetting. The influences of both the surface and the horizons of the soil are therefore included.

Four hydrologic soil groups are used. The soils are classified on the basis of water intake at the end of long-duration storms occurring after prior wetting and an opportunity for swelling and without the protective effects of vegetation. In the definitions to follow, the infiltration rate is the rate at which water enters the soil at the surface and which is controlled by surface conditions. The transmission rate is the rate at which the water moves in the soil and is controlled by the horizons. The hydrologic soil groups, as defined by SCS soil scientists, are:

A. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.

B. Soils having moderate infiltration rates when thoroughly wetted and consisting of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes the downward movement of water or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Appendix B tabulates the hydrologic soil group for each soil series and, in some cases, may list several possible hydrologic soil groupings for a series. In using this table, the first hydrologic group shown is the native or natural group that the soil series is usually classified

under when its water intake characteristics have not been significantly changed by artificial drainage, land use, or other factors. The second group shown is the probable maximum improvement that can be made through artificial drainage and the maintenance or improvement of soil structure. For example, the Adrian soil series is classified as D/A. This means that the natural hydrologic soil group is D. If a field inspection shows that drains and tiles have been constructed to improve the drainage, then the hydrologic soil group may be lowered to A. In general, those soils having several possible classifications are those with relatively high water tables so that artificial drainage measurably improves their ability to absorb rainfall and thus reduce runoff.

Soil surveys have been performed by the SCS and are published in book form. Surveys published since 1970 show the soil type delineations superimposed on an aerial photograph. This format allows for determining land use at the same time the soil determinations are made.

A soil's hydrologic classification may occasionally change based upon updated experimental data defining its infiltration and transmission characteristics. The soils listed in Appendix B were last reviewed and updated in March, 1990.

5. LAND USE

In the SCS method of runoff estimation, the effects of the surface conditions of a watershed are evaluated by means of land use and treatment classes. Land use is the watershed cover and it includes every kind of vegetation, litter and mulch, fallow (bare soil), as well as nonagricultural uses such as water surfaces (lakes, swamps, etc.) and impervious surfaces, such as roads, roofs, etc. Land treatment applies mainly to agricultural land uses and includes mechanical practices such as contouring and terracing and management practices like grazing control and crop rotation. The classes consist of use and treatment combinations actually to be found on watersheds. The following is a brief description of various land uses.

Pasture or range is grassed land that is used for grazing animals. The hydrologic condition is characterized by the degree of grazing and plant cover. Poor condition is that which is heavily grazed that has plant cover on less than half of the area. Fair condition has a moderate amount of grazing with plant cover on ½ to ¾ of the area. Good condition refers to light grazing with plant cover on more than ¾ of the area.

Meadow is a field on which grass is continuously grown, protected from grazing, and generally mowed for hay.

Woods or forest are characterized by their vegetative condition. Poor condition refers to those woods which are either heavily grazed, regularly burned, or have had the undergrowth cleared for recreational uses. Litter, small trees, and brush are absent in this condition. Woods in fair condition may still be grazed but have not been burned. In a good condition, the woods are protected from grazing and litter, small trees, and shrubs cover the soil.

Fallow is the agricultural land use and treatment with the highest potential for runoff. The land is kept as bare as possible to conserve moisture for use by a succeeding crop. The loss due to runoff is offset by the gain due to reduced transpiration.

Row crop is any field crop (corn, soybeans, sugar beets) planted in rows far enough apart that most of the soil surface is exposed to rainfall impact through the growing season.

Small grain (wheat, oats, barley) is planted in rows close enough that the soil surface is not exposed except during planting and shortly thereafter.

Close-seeded legumes or rotation meadow (alfalfa, sweetclover) are either planted in close rows or broadcast. This cover may be allowed to remain for more than a year so that year-round protection is given to the soil.

The four preceding agricultural land uses are also characterized by the farming practice employed. Straight row fields are those farmed in straight rows either up and down the hill or across the slope. Where land slopes are less than about two percent, farming across the slope in straight rows is equivalent to contouring. Contoured fields are those farmed as nearly as possible to conform to the natural land contours. The hydrologic effect of contouring is due to the surface storage provided by the furrows because the storage prolongs the time during which infiltration can take place. Terracing refers to systems containing open-end level or graded terraces, grassed waterway outlets, and contour furrows between the terraces. The hydrologic effects are due to the replacement of a low-infiltration land use by grassed waterways and to the increased opportunity for infiltration in the furrows and terraces.

The four agricultural land uses are further characterized by the crop rotation. Hydrologically, rotations range from "poor" to "good" in proportion to the amount of dense vegetation in the rotation. Poor rotations are generally one-crop land uses such as continuous corn or wheat or combinations of row crops, small grains, and fallow. Good rotations generally contain alfalfa or other close-seeded legume or grass to improve tilth and increase infiltration.

6. RUNOFF CURVE NUMBER

In 1954, the SCS developed a unique procedure for estimating surface runoff from rainfall. This procedure, the Runoff Curve Number (RCN) technique, has proven to be a very useful tool for evaluating effects of changes in land use and treatment on surface runoff. It is the procedure most frequently used within the SCS and by hydrologists nationwide to estimate surface runoff from ungaged watersheds.

The combination of a hydrologic soil group and a land use and treatment class is a hydrologic soil-cover complex. Each combination is assigned a RCN which is an index to its runoff potential on soil that is not frozen. A list of these values is shown in Table 6.1. The tabulated RCN values are for normal soil moisture conditions which is referred to as Antecedent Moisture Condition II (AMC-II). AMC-I has the lowest runoff potential and the watershed soils are dry. AMC-III has the highest runoff potential as the watershed is practically saturated from antecedent rainfall or snowmelt. The AMC can be estimated from the 5-day antecedent rainfall by using Table 6.2. In this table, the "growing" season in Michigan is assumed to be June through September. The limits for "dormant" season apply when the soils are not frozen and there is no snow on the ground.

Although the RCN in Table 6.1 is for AMC-II conditions, an analysis of a specific storm event may require an equivalent RCN for AMC-I or AMC-III. They may be computed by the following equations

$$RCN\,(\,I\,)\ =\ \frac{4.2\ *\ RCN\,(\,II\,)}{10\ -\ 0.058\ *\ RCN\,(\,II\,)} \tag{6.1}$$

and

$$RCN\,(\,III\,)\ =\ \frac{23\ *\ RCN\,(\,II\,)}{10\ +\ 0.13\ *\ RCN\,(\,II\,)} \tag{6.2}$$

A typical watershed is comprised of many different combinations of soil types and land uses. In using the method presented here, the runoff characteristic of the watershed is represented using an average or composite RCN for the entire watershed. The most practical way to determine this is to tabulate each of the four hydrologic groups as a percentage of the total drainage area. Land uses should then be tabulated as a percentage within each specific group along with the appropriate RCN. Multiplying the RCN by the two percentages and summing over all the different soil-cover complexes yields the average watershed RCN. This is illustrated in the following example.

Hydrologic Soil group	% of total Drainage area	Land use	% of soil Group	RCN	Partial RCN
A	30	Meadow	100	30	9.0
B	50	Woods (good cover)	25	55	6.9
		Fallow	75	86	32.3
C	10	Pasture (fair condition)	80	79	6.3
		Woods (poor cover)	20	77	1.5
D	10	Meadow	100	78	7.8
					63.8

In this instance, an average RCN of 64 would be used for this watershed. Tabulating in this manner makes it easier to estimate how a change in land use will alter runoff. Here the bulk of the RCN is contributed by the fallow land use. If all of this land is developed into ¼ acre residential lots (RCN 75), the composite RCN for the watershed would decrease to 60. On the other hand, if all of the fallow land is developed into an industrial area (RCN 88), the average watershed RCN would increase to 65, thereby increasing surface runoff.

This method of computing a composite RCN works very well if all of the individual RCN's are at least 45 or above, where the correlation between RCN and SRO is virtually linear. This method also works well if all of the individual RCN's are less than 45. But there may be an occasion where the watershed has a significant amount of very low RCN's and a large amount of very high ones. Since the RCN/SRO relationship becomes less linear for the very low

Table 6.1 Runoff curve numbers for hydrologic soil-cover complexes

(AMC-II conditions)

Land use	Treatment or practice	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow	Straight row		77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	"	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	" and terraced	Poor	66	74	80	82
	" " "	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	"	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	"	Good	61	73	81	84
	" and terraced	Poor	61	72	79	82
	" " "	Good	59	70	78	81
Close-seeded legumes or rotation meadow	Straight row	Poor	66	77	85	89
	"	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	"	Good	55	69	78	83
	" and terraced	Poor	63	73	80	83
	" " "	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	"	Fair	25	59	75	83
	"	Good	6	35	70	79
Meadow			30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Residential						
⅛ acre			77	85	90	92
¼ acre			61	75	83	87
1/3 acre			57	72	81	86
½ acre			54	70	80	85
1 acre			51	68	79	84
Open spaces (parks, golf courses, cemeteries, etc.)						
Good condition: Grass cover > 75% of area			39	61	74	80
Fair condition: " " 50-75% of area			49	69	79	84
Commercial or business area (85% impervious)			89	92	94	95
Industrial district (72% impervious)			81	88	91	93
Farmsteads			59	74	82	86
Paved areas (roads, driveways, parking lots, roofs)			98	98	98	98
Water surfaces (lakes, ponds, reservoirs, etc.)			100	100	100	100
Swamp At least 1/3 is open water			85	85	85	85
Swamp Vegetated			78	78	78	78

RCN's, proportioning the RCN to compute a composite value as described above will produce a RCN which underestimates the correct amount of runoff. In this instance, a more accurate runoff estimate is made by computing the incremental SRO for each land use and summing these to obtain the total runoff. Equations 6.1 and 6.2 may then be solved to yield the composite RCN, if desired. This method of weighting the runoff requires more work than simply proportioning the RCN's. It should only be needed if more than 20 percent of the watershed has RCN's less than 45 with most of the remaining RCN's at the higher end of the scale.

Table 6.2   Seasonal rainfall limits for AMC

Total 5-day antecedent rainfall (inches)

AMC group	Dormant season	Growing season
I	< 0.5	< 1.4
II	0.5 - 1.1	1.4 - 2.1
III	> 1.1	> 2.1

7. SURFACE RUNOFF

The total precipitation (P) in a storm can be divided into three paths that the water will follow in the hydrologic cycle. There is some initial amount of rainfall (I_a) for which no runoff will occur. This quantity is the initial abstraction and consists of interception, evaporation, and the soil-water storage that must be satisfied before surface runoff may begin. After this initial abstraction is met, the soil has a continuing abstraction capacity (F), depending on the type of soil. A rainfall rate greater than this continuing abstraction is surface runoff (SRO). These quantities can be described by the equation:

$$P = SRO + I_a + F \tag{7.1}$$

While F is a continuing abstraction, there is a potential maximum retention S characteristic to each RCN. The hypothesis of the SCS method is that the ratio of F to S is equal to the ratio of the actual runoff SRO to the potential maximum runoff, P - I_a. This is expressed as

$$\frac{F}{S} = \frac{SRO}{P - I_a} \tag{7.2}$$

Combining (7.1) and (7.2) to solve for SRO:

$$SRO = \frac{(P - I_a)^2}{P - I_a + S} \tag{7.3}$$

An empirical relation was developed by studying many small experimental watersheds:

$$I_a = 0.2 * S \tag{7.4}$$

Substituting this into (7.3) produces:

$$SRO = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{7.5}$$

where:
$$S = \frac{1000}{RCN} - 10 \tag{7.6}$$

where S is in inches. Therefore, given RCN for a watershed and a design rainfall, equations (7.5) and (7.6) can be solved to compute the surface runoff.

8. TIME OF CONCENTRATION

Time of concentration (T_c) is the time it takes for runoff to travel from the hydraulically most distant point in the watershed to the design point. In hydrograph analysis, T_c is the time from the end of rainfall excess to the inflection point on the falling limb of the hydrograph. This point signifies the end of surface runoff and the beginning of baseflow recession. The T_c may vary between different storms, especially if the rainfall is nonuniform in either areal coverage or intensity. However, in practice, T_c is considered to be constant.

Measuring from a recorded hydrograph provides the most accurate estimate of T_c. For ungaged watersheds, T_c is calculated by estimating the velocity through the various components of the stream network. There are many methods used to estimate the velocity. The method presented in this report expresses velocity in the form

$$V = K * S^{0.5} \tag{8.1}$$

where K is a coefficient depending on the type of flow, S is the slope of the flow path in percent, and V is the velocity in feet per second.

Three flow types are used based on their designation on U.S. Geological Survey topographic maps.

Small tributary:	Permanent or intermittent streams which appear as a solid or dashed blue line on the topo maps. This also applies to a swamp that has a defined stream channel.
Waterway:	This is any overland route which is a well-defined swale by elevation contours but does not have a blue line denoting a defined channel. This also applies to a swamp that does not have a defined channel flowing through it.
Sheet Flow:	This is any overland flow path which does not conform to the waterway definition.

An illustration of each of these flow types is included in the example in Appendix A. The coefficients for each of these in equation (8.1) are

Flow type	K
Small tributary	2.1
Waterway	1.2
Sheet flow	.48

These coefficients were derived by Richardson (1969) as a means of estimating velocities when detailed stream hydraulic data are unavailable.

Once the velocity is determined, time of concentration can be computed as

$$T_c = \frac{L}{V * 3600} \tag{8.2}$$

where L is the length in feet of the particular flow path and the factor 3600 converts T_c from seconds to hours.

In most watersheds, all three flow types will be present. Starting at the basin divide, the runoff may proceed from sheet flow to waterway, back to sheet flow, then waterway again, then small tributary, etc. The T_c for each segment should be computed and then summed to give the total T_c.

It is important that the length used to compute T_c has a uniform slope. As an example, assume a 5000 foot length of small tributary has a change in elevation of 10.4 feet. This slope of 0.208% produces a T_c of 1.45 hours. However, if it is known that the upper 1000 feet of this stream falls 10 feet and the lower 4000 feet only falls 0.4 feet, then this would produce a total T_c of 5.42 hours. Therefore, it is best to sum T_c over the smallest possible contour interval which is usually 5 or 10 feet on most topo maps. This interval can be enlarged if a visual examination of the topo map shows a uniform spacing between successive contour crossings.

9. UNIT HYDROGRAPH PEAK

The unit hydrograph peak (Q_p) is a function of travel time through the stream system or T_c. An expression relating Q_p to T_c was developed in the following manner.

Discharges were computed for a hypothetical watershed having a drainage area of 1 mi^2, a RCN of 75, and a 24-hour design rainfall of 5 inches using the SCS Type II rainfall distribution. The discharges were computed using the TR-20 computer program developed by the SCS. However, in lieu of using the standard dimensionless UH in TR-20, these simulations used the UH determined from the gage analysis discussed in Section 2 of this report.

The T_c for this hypothetical basin was varied from 1 hour to 40 hours. The peak discharge for each different T_c was divided by the amount of surface runoff to obtain Q_p which has the units of cfs per inch of runoff per square mile of drainage area. The data set of Q_p versus T_c was analyzed using a log-linear regression to obtain:

$$Q_p = 238.6 * T_c^{-0.82} \qquad\qquad (9.1)$$

10. ADJUSTMENTS FOR SURFACE PONDING

Peak flows determined in this method assume that the topography is such that surface flow into ditches, drains, and streams is approximately uniform. In areas where ponding or swampy areas occur in the watershed, a considerable amount of surface runoff may be retained in temporary storage. The peak rate of runoff should be reduced to reflect this condition. Table 10.1 provides adjustment factors to determine this reduction based on the ratio of ponding or swampy area to the total drainage area for a range of flood frequencies. The three sections of this table provide different adjustment factors depending on where the ponding occurs in the watershed. These values were determined by the SCS (1975) from experimental watersheds of less than 2000 acres. These factors may still be used for larger basins until newer data become available. For percentages beyond the range in the tables, the data may be extrapolated on semi-log paper with the reduction factor on the log scale.

In some cases, it is appropriate to apply the ponding adjustment more than once. For example, assume a watershed has two percent ponding scattered throughout and a lake that is one percent of the drainage area located at the design point. If the 100-year frequency flood is being determined, the peak flow should be multiplied by 0.87 for the scattered ponding and further reduced by 0.89 for the lake. This produces a total reduction factor of 0.77. However, if the inflow to the lake is to be analyzed using a reservoir routing procedure, then only the reduction factor of 0.87, representing the scattered ponding, should be applied.

Table 10.1 Adjustment factors for ponding

Percentage of ponding and swampy area	Storm frequency (years)					
	2	5	10	25	50	100
Ponding occurs in central parts of the watershed or is spread throughout						
0.2	.94	.95	.96	.97	.98	.99
0.5	.88	.89	.90	.91	.92	.94
1.0	.83	.84	.86	.87	.88	.90
2.0	.78	.79	.81	.83	.85	.87
2.5	.73	.74	.76	.78	.81	.84
3.3	.69	.70	.71	.74	.77	.81
5.0	.65	.66	.68	.72	.75	.78
6.7	.62	.63	.65	.69	.72	.75
10	.58	.59	.61	.65	.68	.71
20	.53	.54	.56	.60	.63	.68
Ponding occurs only in upper reaches of watershed						
0.2	.96	.97	.98	.98	.99	.99
0.5	.93	.94	.94	.95	.96	.97
1.0	.90	.91	.92	.93	.94	.95
2.0	.87	.88	.88	.90	.91	.93
2.5	.85	.85	.86	.88	.89	.91
3.3	.82	.83	.84	.86	.88	.89
5.0	.80	.81	.82	.84	.86	.88
6.7	.78	.79	.80	.82	.84	.86
10	.77	.77	.78	.80	.82	.84
20	.74	.75	.76	.78	.80	.82
Ponding occurs at the design point						
0.2	.92	.94	.95	.96	.97	.98
0.5	.86	.87	.88	.90	.92	.93
1.0	.80	.81	.83	.85	.87	.89
2.0	.74	.75	.76	.79	.82	.86
2.5	.69	.70	.72	.75	.78	.82
3.3	.64	.65	.67	.71	.75	.78
5.0	.59	.61	.63	.67	.71	.75
6.7	.57	.58	.60	.64	.67	.71
10	.53	.54	.56	.60	.63	.68
20	.48	.49	.51	.55	.59	.64

11. SUMMARY OF METHOD

This section summarizes the steps needed to compute discharges using the procedures in this report.

1.   Delineate the watershed boundaries on a topographic map and measure the drainage area. If there are areas within this boundary which are either deep depressions or otherwise do not contribute any runoff, then measure these and delete them from the total drainage area. The area remaining is termed the 'contributing drainage area' and is the portion of the watershed which will be used in subsequent calculations.

[Note: Some judgement needs to be used when defining noncontributing areas. If a topo map with a five foot contour interval shows two nested depression contours, then we know that portions of the entire depression are at least five feet deep. The volume of the depression can be calculated and compared to the volume of runoff which drains into it. If it can contain all of the runoff, the entire area draining into the depression may be deleted as 'noncontributing area'. However, if the topo map only shows a single depression contour, it could be anywhere from a few inches deep to just under five feet deep. In this case, there is no definitive way to tell how much runoff this depression can store. In this instance, it may be necessary to conduct a field inspection of the watershed to ascertain the storage potential of the depression area.]

2.   Overlay the boundaries of the contributing drainage area on soil and land use maps and tabulate the hydrologic soil-cover complexes in the watershed. Assign curve numbers using Table 6.1 and calculate the average RCN as outlined in Section 6.

3.   Starting at the design point and working upstream, tabulate incremental times of concentration using the procedure in section 8. When reaching a junction of two or more streams, follow the one which has the largest contributing drainage area. After reaching the most upstream point (as defined by a blue line on topo maps), determine any additional contribution to T_c due to overland flow paths. Add all of the incremental times of concentration to determine the watershed T_c. Compute Q_p using equation 9.1.

4.   Select a design frequency and determine the 24-hour rainfall from Table 3.1. If the contributing drainage area is greater than 10 square miles, then adjust the rainfall using Table 3.2.

5.   Using the average RCN computed in step 2, calculate the surface runoff for the selected design event using equations 7.5 and 7.6.

6.   Compute the design discharge by multiplying Q_p (step 3) times the contributing drainage area (step 1) times SRO (step 5). If there are ponding or swampy areas in the watershed, adjust this computed discharge as outlined in Section 10.

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Appendix A   Sample application

The bridge at the Brocker Road crossing of the example watershed needs to be replaced. The watershed which contributes runoff to this point, which is depicted in Figure A.1, has a drainage area of 2.43 square miles and is undergoing urbanization. All of the areas which are currently either pasture or meadow will be developed into ¼ acre residential subdivisions. What effect will this have on the design flood produced by the 100-year, 24-hour rainfall?

Figure A.1 is an enlargement of a USGS topographic map. The contour interval for this map is 10 feet. In this figure, a thick black line is used to denote the watershed boundary, while the prominent, but thinner, black line inside the boundary shows the small tributaries in the basin. The irregularly shaped black areas show the locations of lakes and ponds, while the lighter gray patches show the wooded portions of the watershed. The following table shows the different soil groups and associated land uses as they currently exist in the watershed.

Hydrologic Soil group	% of total Drainage area	Land use	% of soil Group	RCN	Partial RCN
A	7	Meadow	25	30	.5
		Pasture (fair)	15	49	.5
		Row crop (cont./good)	60	65	2.7
B	84	Small grain (cont./good)	60	73	36.8
		Pasture (fair condition)	25	69	14.5
		Woods (poor cover)	10	66	5.5
		Meadow	5	58	2.4
D	9	Meadow	35	78	2.5
		Woods (good cover)	5	77	.3
		Lakes and ponds	15	100	1.4
		Swamps (vegetated)	35	78	2.5
		Swamps (open water)	10	85	.8
					70.4

Deleting the contribution from meadows and pastures and replacing them with the RCN's for the residential lots changes the composite RCN to 73.4. Common practice is to round off the computed RCN, so this watershed would have curve numbers of 70 and 73 to represent existing and proposed development conditions, respectively.

The time of concentration is computed along the stream which flows in a northeastward direction from the headwaters in Section 36. There is also a small portion of waterway and sheet flow upstream from the end of the small tributary. The small tributary portions were generally divided into lengths which correspond with the contour interval of the topo map. The following table shows the computations:

Type of flow	Length (ft)	Δ Ele (ft)	Slope (%)	V (fps)	Incremental T_c (hr)
Small trib	1640	12	.73	1.80	.25
" "	1380	10	.73	1.79	.21
" "	1970	10	.51	1.50	.37
" "	1520	10	.66	1.70	.25
" "	6870	8	.12	.72	2.66
Waterway	1840	2	.11	.40	1.29
Sheet	150	22	14.67	1.84	.02
					5.05

Summing the incremental T_c's produces a total T_c of 5.05 hours. Substituting this into equation (9.1) produces a peak discharge of 63.24 cfs per square mile per inch of runoff. The table shows that the slope of the small tributary is not uniform over its entire length. If the slope is calculated as a 50 foot drop over the 13,400 foot length, the resulting total T_c is 4.21 hours. This produces a Q_p of 65.79 cfs/mi^2-in. Thus, the design discharge would have been 13 percent higher because of an error in calculating T_c. This illustrates the importance of using the most refined data available, in this case, the distance between successive 10-foot contours.

The 100-year, 24-hour rainfall obtained from Table 3.1 is 4.36 inches. Using this value and the previously computed RCN's, the runoff can be determined using equations (7.5) and (7.6). For existing conditions (RCN=70), the runoff is 1.57 inches. The runoff for proposed development conditions (RCN=73) is 1.79 inches.

The design discharge is obtained by simply multiplying the computed Q_p by the drainage area and the computed runoff. These results are:

Existing: $Q = 63.24$ cfs/mi^2-in $* 2.43$ mi$^2 * 1.57$ in

$= 241$ cfs

Proposed: $Q = 275$ cfs

These numbers need to be adjusted for ponding. The land use table shows that 5.4 percent of the watershed is either open water or swamps. These areas are spread uniformly throughout the basin. An adjustment factor of 0.77 can be interpolated from Table (10.1). The final design discharges are:

Existing: $Q = 241 * 0.77$

$= 186$ cfs

Proposed: $Q = 212$ cfs

Figure A.1   Example watershed
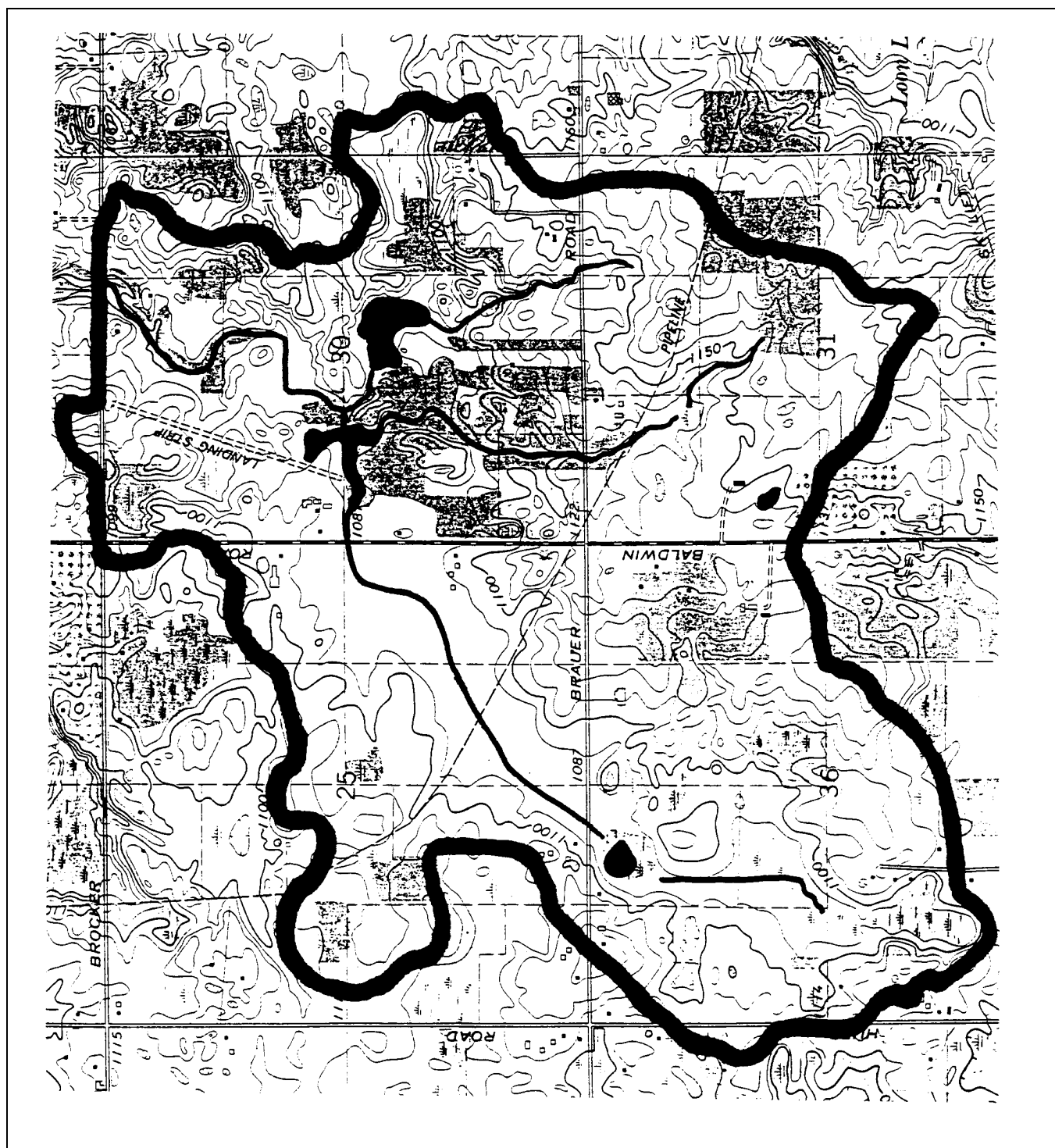
Appendix B Hydrologic soil groups for Michigan soils

Soil series	Hyd. Group	Soil series	Hyd. Group	Soil series	Hyd. Group
Abbaya	B	Brassar	C	Dighton	B
Abscota	A	Breckenridge	D/B	Dixboro	B
Adrian	D/A	Brems	A	Dora	D/B
Alcona	B	Brevort	D/B	Dowagiac	B
Algansee	B	Brimley	B	Dresden	B
Allendale	B	Bronson	B	Dryburg	B
Allouez	B	Brookston	D/B	Dryden	B
Alpena	A	Bruce	D/B	Duel	A
Alstad	C	Burleigh	D/A	Dungridge	B
Amasa	B	Burt	D	East Lake	A
Angelica	D/B	Cadmus	B	Eastport	A
Arkona	B	Capac	C	Edmore	D
Arkport	B	Carbondale	D/A	Edwards	D/B
Arnheim	D	Carlisle	D/A	Eel	B
Ashkum	D/B	Caasopolis	B	Eleva	B
Assinins	B	Cathro	D/A	Elmdale	B
Aubarque	D/C	Celina	C	Elston	B
Aubbeenaubbee	B	Ceresco	B	Elvers	D/B
Au Gres	B	Champion	B	Emmet	B
Aurelius	D/B	Channahon	D	Ensign	D
Avoca	B	Channing	B	Ensley	D/B
Bach	D/B	Charity	D	Epoufette	D/B
Badaxe	B	Charlevoix	B	Epworth	A
Banat	B	Chatham	B	Ermatinger	D/B
Barry	D/B	Cheboygan	B	Esau	A
Battlefield	D/A	Chelsea	A	Escanaba	A
Beavertail	D	Chesaning	B	Essexville	D/A
Beechwood	C	Chestonia	D	Evart	D
Belding	B	Chippeny	D	Fabius	B
Belleville	D/B	Cohoctah	D/B	Fairport	C
Benona	A	Coloma	A	Fence	B
Bergland	D	Colonville	C	Fibre	D/B
Berville	D/B	Colwood	D/B	Filion	D
Biscuit	D/B	Conover	C	Finch	C
Bixby	B	Coral	C	Fox	B
Bixler	C	Corunna	D/B	Frankenmuth	C
Blount	C	Coupee	B	Frenchette	B
Blue Lake	A	Covert	A	Freda	D
Bohemian	B	Crosier	C	Froberg	D
Bonduel	C	Croswell	A	Fulton	D
Bono	D	Cunard	B	Gaastra	C
Boots	D/A	Cushing	B	Gagetown	B
Borski	B	Dawson	D/A	Gay	D/B
Bowers	C	Deer Park	A	Genesee	B
Bowstring	D/A	Deerton	A	Gilchrist	A
Boyer	B	Deford	D/A	Gilford	D/B
Brady	B	Del Rey	C	Gladwin	A
Branch	B	Detour	B	Glawe	D/B

Two soil groups such as D/B indicates the undrained/drained condition

Soil series	Hyd. Group	Soil series	Hyd. Group	Soil series	Hyd. Group
Glendora	D/A	Keowns	D/B	Miami	B
Glynwood	C	Kerston	D/A	Michigamme	C
Gogebic	B	Keweenaw	A	Millsdale	D/B
Gogomain	D/B	Kibbie	B	Milton	C
Goodman	B	Kidder	B	Minoa	C
Gorham	D/B	Kilmanagh	C	Minocqua	D/B
Grace	B	Kingsville	D/A	Minong	D
Granby	D/A	Kinross	D/A	Misery	C
Grattan	A	Kiva	A	Mitiwanga	C
Graveraet	B	Klacking	A	Moltke	B
Graycalm	A	Kokomo	D/B	Monico	C
Grayling	A	Koontz	D	Monitor	C
Greenwood	D/A	Krakow	B	Montcalm	A
Grindstone	C	Lacota	D/B	Moquah	B
Grousehaven	D	Lamson	D/B	Morley	C
Guardlake	A	Landes	B	Morocco	B
Guelph	B	Lapeer	B	Mudsock	D/B
Gutport	D	Latty	D	Munising	B
Hagensville	C	Leelanau	A	Munuscong	D/B
Halfaday	A	Lenawee	D/B	Mussey	D/B
Hatmaker	C	Leoni	B	Nadeau	B
Henrietta	D/B	Liminga	A	Nahma	D/B
Hessel	D/B	Linwood	D/A	Napoleon	D/A
Hettinger	D/C	Locke	B	Nappanee	D
Hillsdale	B	Lode	B	Nester	C
Hodenpyl	B	London	C	Net	C
Houghton	D/A	Longrie	B	Newaygo	B
Hoytville	D/C	Loxley	D/A	Newton	D/A
Huntington	B	Lupton	D/A	Nottawa	B
Ingalls	B	Mackinac	B	Nunica	C
Ingersoll	B	Macomb	B	Oakville	A
Ionia	B	Mancelona	A	Ockley	B
Iosco	B	Manistee	A	Oconto	B
Isabella	B	Manitowish	B	Ocqueoc	A
Ishpeming	A	Markey	D/A	Ogemaw	D/C
Ithaca	C	Marlette	B	Okee	B
Jacobsville	D	Martinsville	B	Oldman	C
Jeddo	D/C	Martisco	D/B	Olentangy	D/A
Jesso	C	Matherton	B	Omega	A
Johnswood	B	Maumee	D/A	Omena	B
Kalamazoo	B	McBride	B	Onaway	B
Kalkaska	A	Mecosta	A	Onota	B
Kallio	C	Melita	A	Ontonagon	D
Karlin	A	Menagha	A	Ormas	B
Kawbawgam	C	Menominee	A	Oshtemo	B
Kakkawlin	C	Mervin	D/A	Otisco	A
Kendallville	B	Metamora	B	Ottokee	A
Kent	D	Metea	B	Owosso	B

Two soil groups such as D/B indicates the undrained/drained condition

Soil series	Hyd. Group	Soil series	Hyd. Group	Soil series	Hyd. Group
Paavola	B	Saganing	D/A	Thomas	D/B
Padus	B	Sanilac	B	Tobico	D/A
Palms	D/A	Saranac	D/C	Toledo	D
Parkhill	D/B	Sarona	B	Tonkey	D/B
Paulding	D	Satago	D	Toogood	A
Pelkie	A	Saugatuck	C	Trenary	B
Pella	D/B	Saylesville	C	Trimountain	B
Pemene	B	Sayner	A	Tula	C
Pence	B	Scalley	B	Tuscola	B
Pendleton	C	Schoolcraft	B	Tustin	B
Pequaming	A	Sebewa	D/B	Twining	C
Perrin	B	Selfridge	B	Tyre	D/A
Perrinton	C	Selkirk	C	Ubly	B
Pert	D	Seward	B	Velvet	C
Peshekee	D	Shebeon	C	Vestaburg	D/A
Petticoat	B	Shelldrake	A	Vilas	A
Pewamo	D/C	Shelter	B	Volinia	B
Pickford	D	Shiawassee	C	Wainola	B
Pinconning	D/B	Shinrock	C	Waiska	B
Pinnebog	D/A	Shoals	C	Wakefield	B
Pipestone	B	Sickles	D/B	Wallace	B
Plainfield	A	Sims	D	Wallkill	D/C
Pleine	D	Sisson	B	Warners	D/C
Ponozzo	C	Skanee	C	Wasepi	B
Posen	B	Sleeth	C	Washtenaw	D/C
Poseyville	C	Sloan	D/B	Watton	C
Potagannissing	D	Solona	C	Waucedah	D
Poy	D	Soo	D/C	Wauseon	D/B
Proctor	B	Sparta	A	Wautoma	D/B
Randolph	C	Spinks	A	Wega	B
Rapson	B	Springlake	A	Westbury	C
Remus	B	St. Clair	D	Whalan	B
Rensselaer	D/B	St. Ignace	D	Wheatley	D/A
Richter	B	Stambaugh	B	Whitaker	C
Riddles	B	Steuben	B	Whitehall	B
Rifle	D/A	Sturgeon	B	Willette	D/A
Riggsville	C	Sugar	B	Winneshiek	B
Rimer	C	Summerville	D	Winterfield	D/A
Riverdale	A	Sundell	B	Wisner	D/B
Rockbottom	B	Sunfield	B	Witbeck	D/B
Rockcut	B	Superior	D	Wixom	B
Rodman	A	Tacoosh	D/B	Wolcott	D/B
Ronan	D	Tallula	B	Woodbeck	B
Rondeau	D/A	Tamarack	B	Yalmer	B
Roscommon	D/A	Tappan	D/B	Ypsi	C
Roselms	D	Tawas	D/A	Zeba	B
Rousseau	A	Teasdale	B	Ziegenfuss	D
Rubicon	A	Tedrow	B	Zilwaukee	D
Rudyard	D	Tekenink	B	Zimmerman	A
Ruse	D	Thetford	A		

Two soil groups such as D/B indicates the undrained/drained condition